Simulations of beam-gas background in eRHIC

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BNL EIC Science Task Force Meeting

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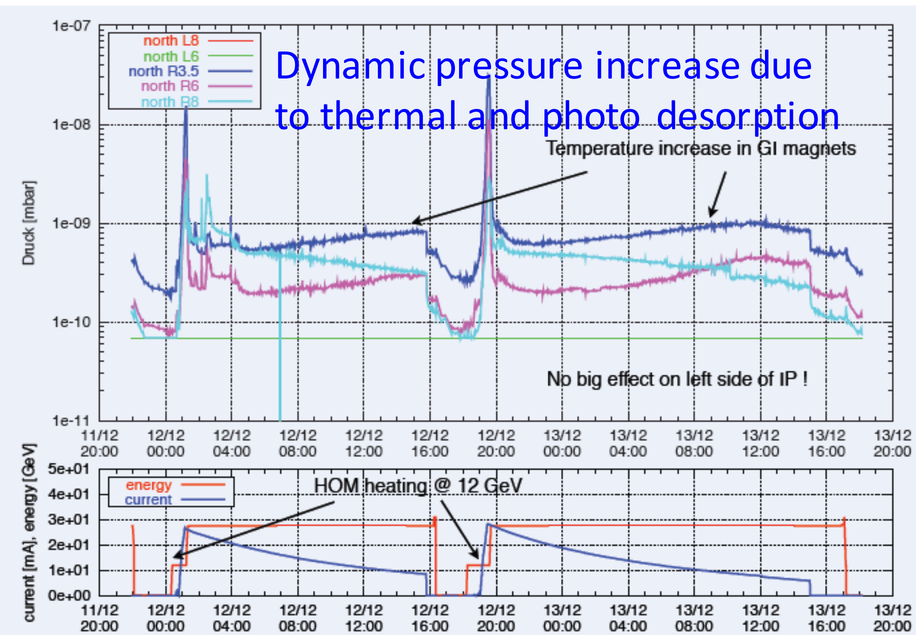
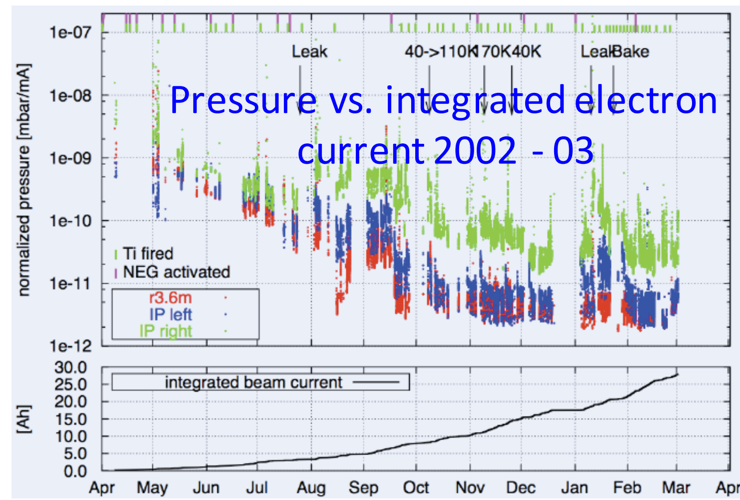
Motivation

- One source of background to physics analyses is from beam-gas interactions
- Beam-gas → interaction of the beam with residual gas in the beampipe
- This was an issue at HERA (especially after the upgrade to HERA-II)
  - Beam squeezed at the IP to increase luminosity
  - Observed increased background rates → several month shutdown
  - Proton beam-gas interactions were the most severe background
    - Needed improved vacuum
- This study marks the beginning of this investigation for the specific case of eRHIC
- Study can be used to guide overall IR design, figure out where mask and dumps need to be
- Also will place limits on the level of vacuum needed
- Current study focuses on proton beam-gas interactions
- p+A cross section is large compared to e+p cross-section
  - $p+H^2$ (250 GeV p) → 60 mb (not including elastic)
  - p+Ar (250 GeV p) → 600 mb (not including elastic)
  - e+p (10 x 250 GeV) → 0.05 mb

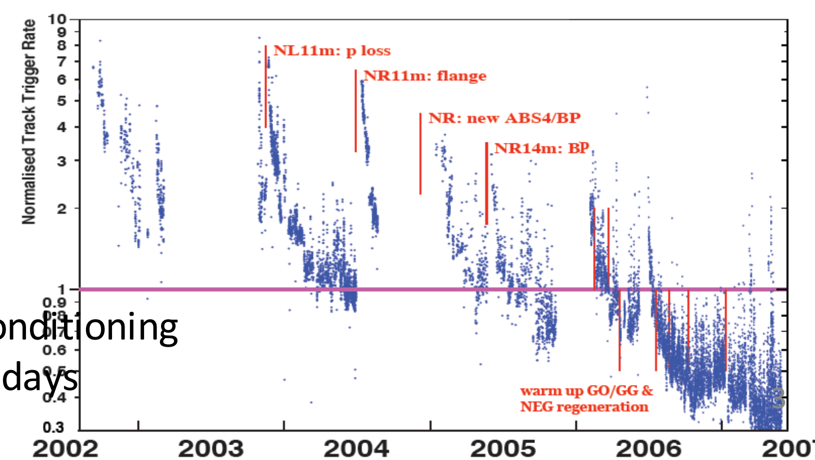
Some lessons from the HERA II upgrade

- Seemed to be a convoluted problem that combined heating of beam pipe and/or breaking of vacuum due to high levels of synchrotron radiation
  - Lead to dynamic pressure increase → greater proton beam-gas background
  - Needed long conditioning to clear out





Proton Beam Gas Background



Two time constants for vacuum conditioning

- Short term after leaks 20 – 30 days
- Long term 600 days

Tools used for the study

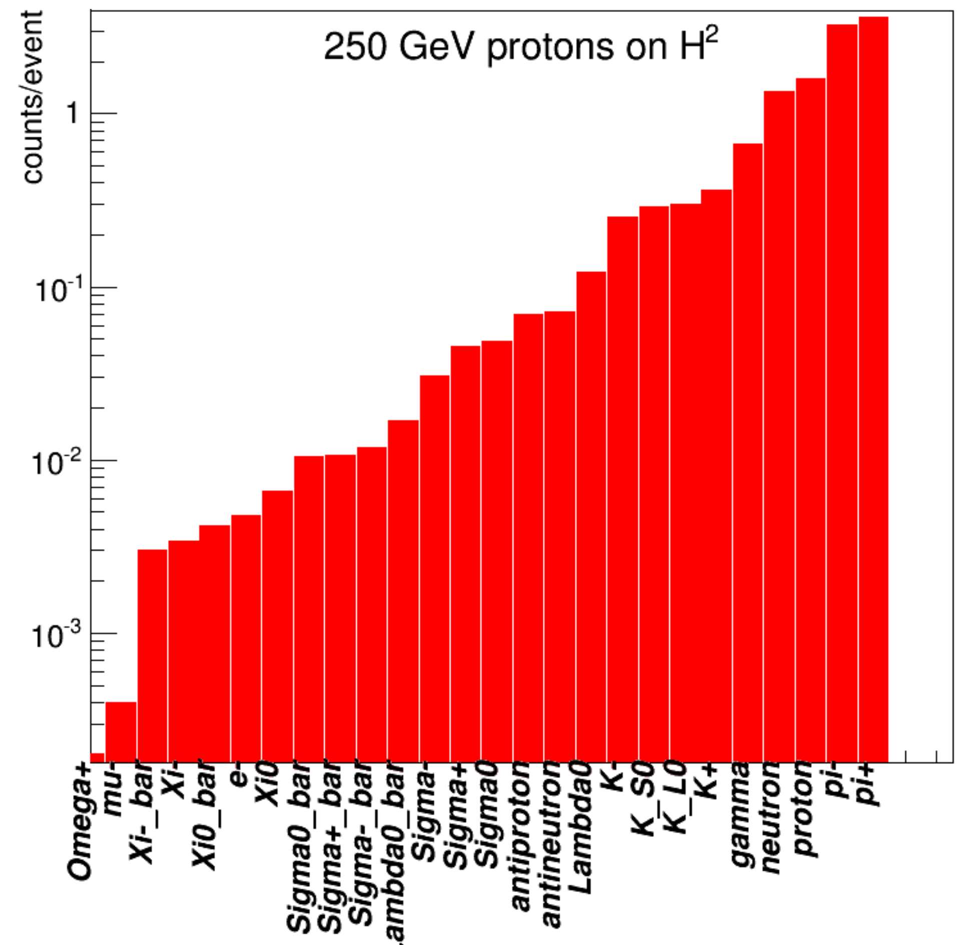
- Dpmjet3: simulation of p+A collisions representing the background processes
  - https://wiki.bnl.gov/eic/index.php/DPMJet
- Pythia: simulation of e+p for estimating physics signal
  - https://wiki.bnl.gov/eic/index.php/PYTHIA
- EicRoot: GEANT simulation package implementing IR magnets and detectors
  - https://wiki.bnl.gov/eic/index.php/Eicroot

Baseline background simulations

- Strategy:
  - Simulate stand-alone p+A collisions (dpmjet3)
  - Displace vertex of collisions along the beam orbit in a given IR setup
  - Send modified event record into EicRoot and track the produced particles through the IR and into the detector
    - Interaction of particles with magnet material is suppressed
- Metrics:
  - Overall rate of particles hitting the detector
  - Probability of background event overlapping with physics event
  - Investigating what areas of the detector get hit the most and by what type of particle

Baseline background simulations

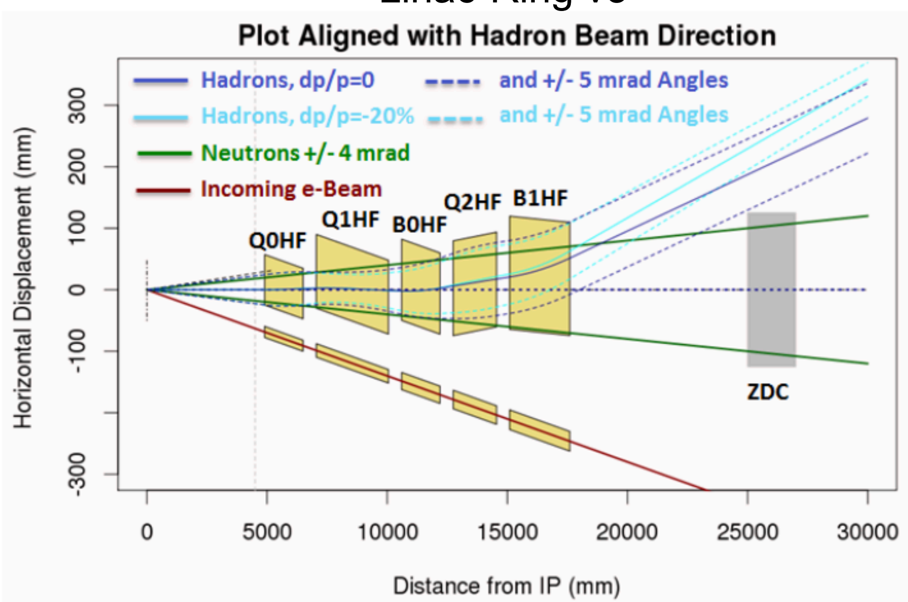
- Simulate fixed target p+H[2] collisions (p at 250 GeV)
  - Choose H[2] because RHIC vacuum group claim that at least 90% of residual gas in pipe is H[2]



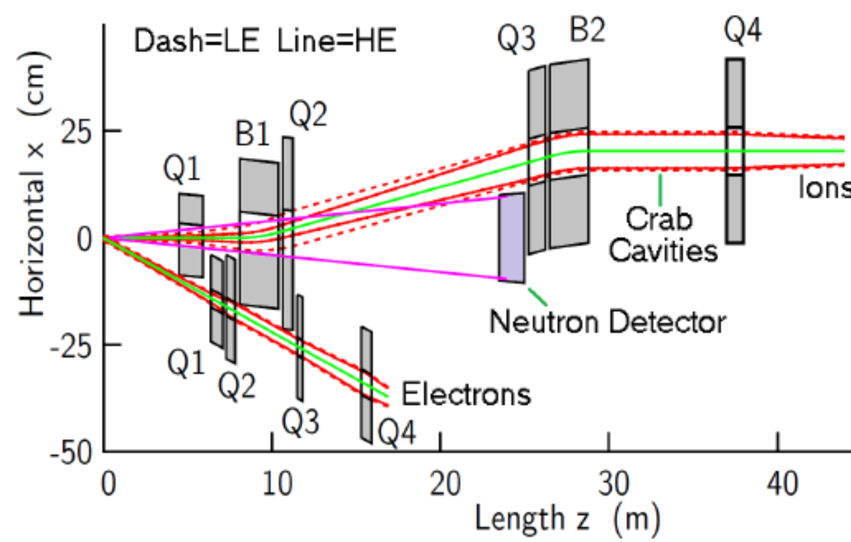
Where do background event particles go?

- Track particles with the information in the TGeoTrack class
    - Contains individual space points of the track trajectory, in addition to momentum/particle type/vertex information
- Consider a particle to hit the detector if a space point for the track is found that has simultaneously:
    - -4.5 < z < 4.5 m
    - Radius from beamline > 2 cm (outside of beam pipe)

Linac-Ring v3

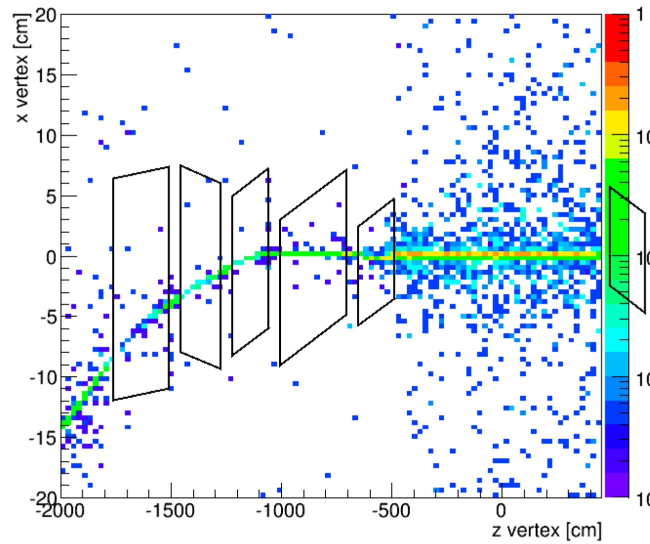


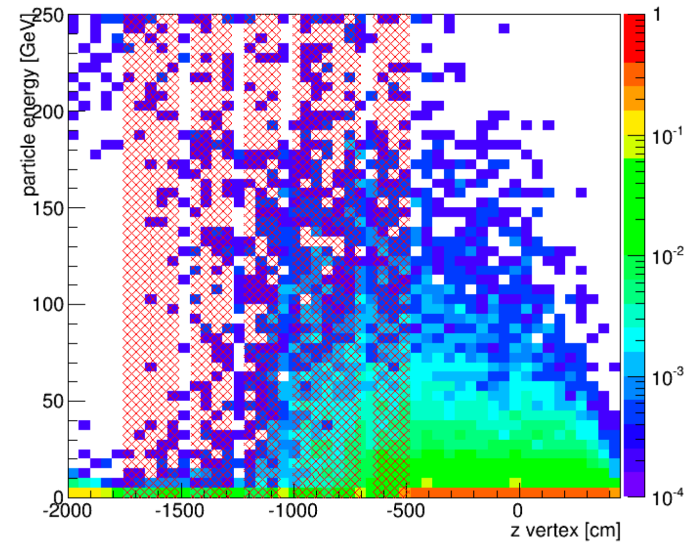
Ring-Ring v2



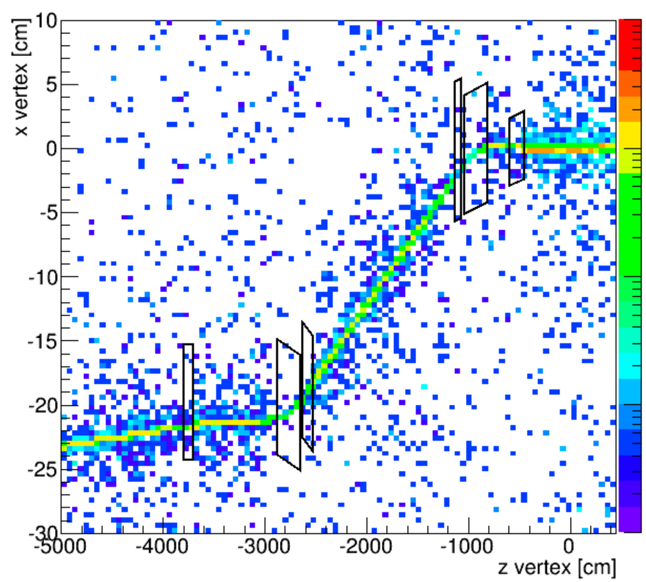
Where do background events that hit the detector come from?

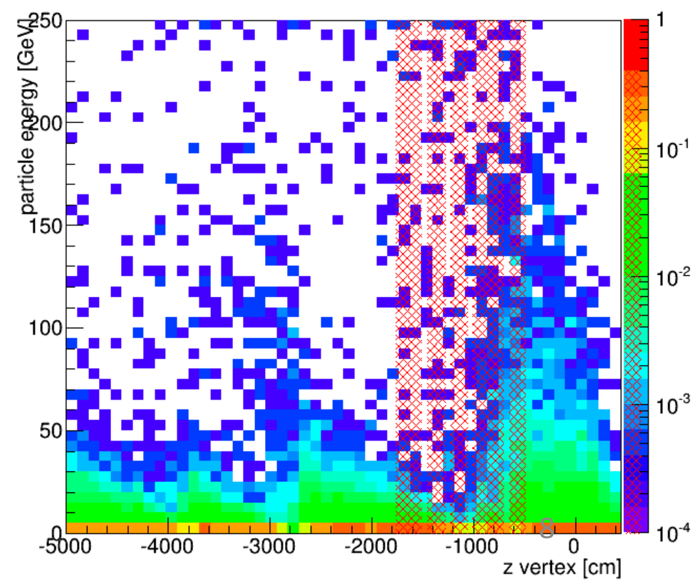
LRv3



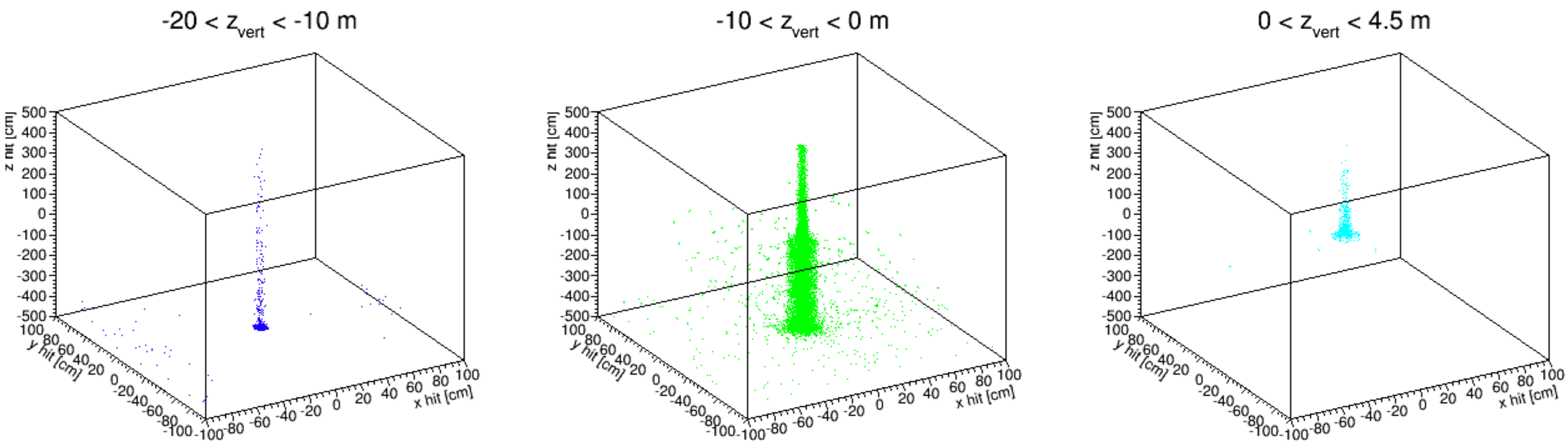


RRv2

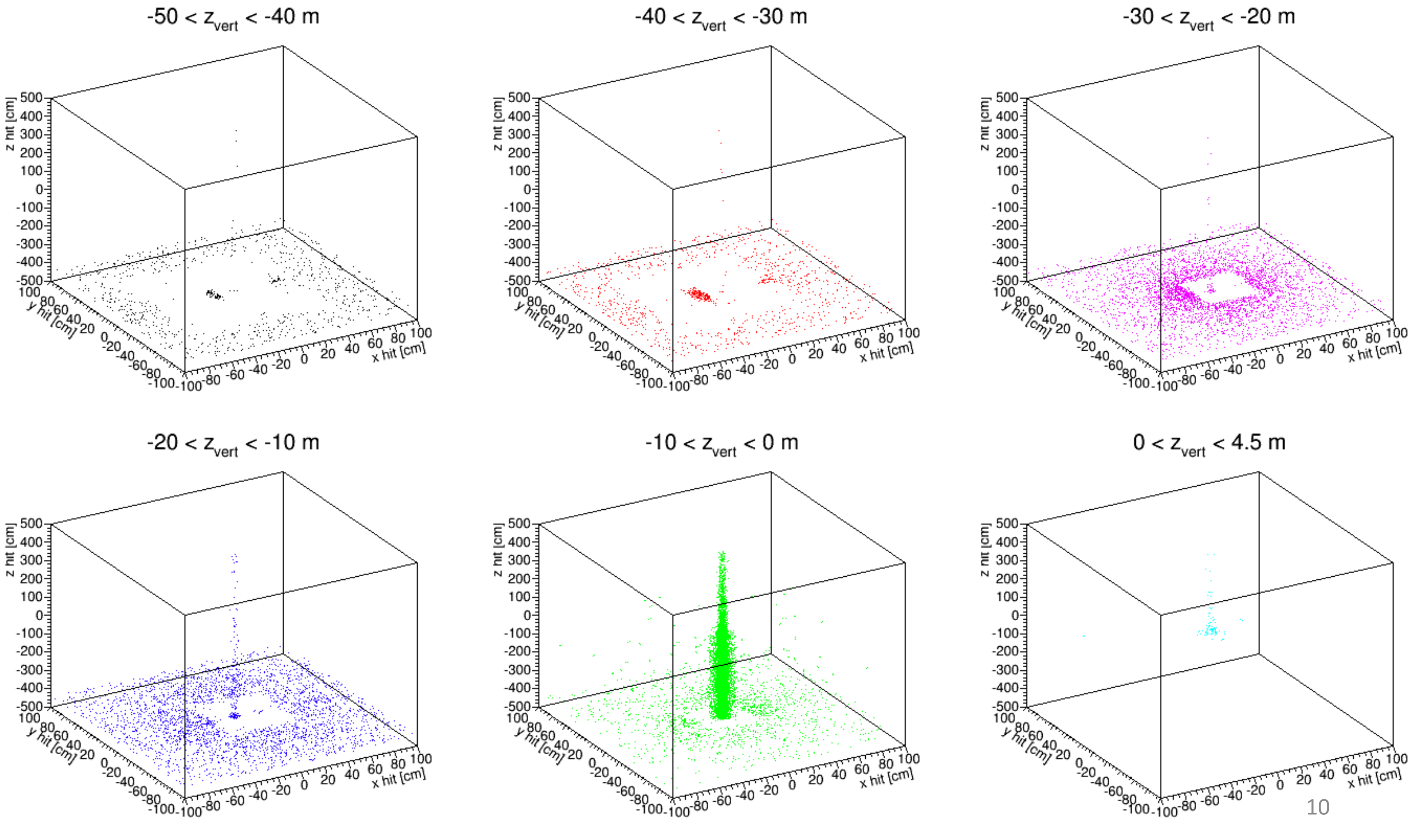




Where do the background particles hit the detector (LRv3)?



Where do the background particles hit the detector (RRv2)?



Calculating the rate of background events

- Estimate the luminosity of background collisions using the proton beam current and the gas density

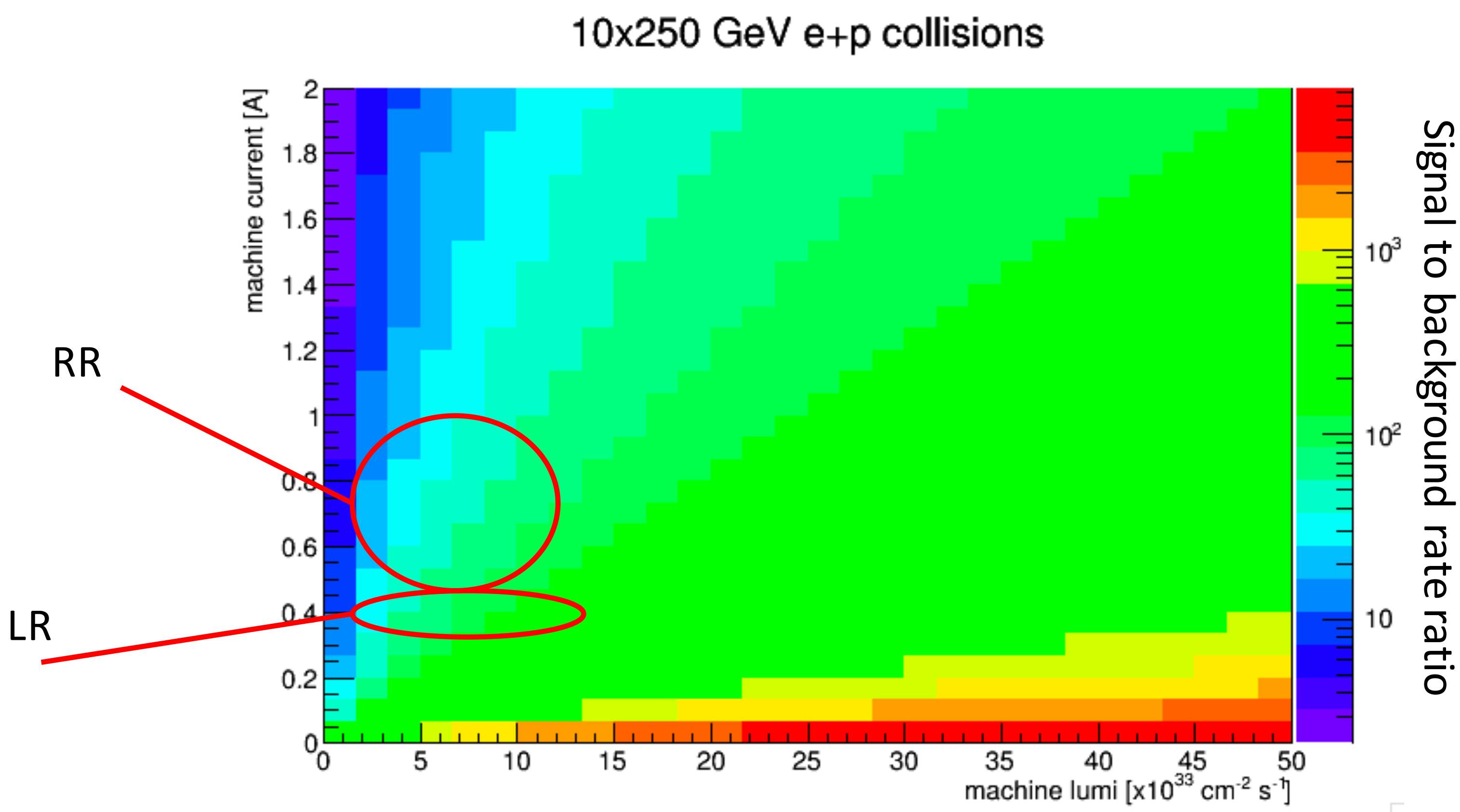
$$L = \Phi \cdot \rho \cdot l$$

- The gas density is estimated from the vacuum at HERA of 10^{-9} mbar or 2.65×10^{7} molecules/cm^3
  - gas density assumed uniform along beam pipe

Machine Design	Rep. Rate [MHz]	Beam energy (e+p) [GeV]	Proton current [mA]	Background Lumi [x 10^{29} $cm^{-2}s^{-1}$]
Linac-ring (low risk)	9.4	13 x 275	415	1.8
Linac-ring (ultimate)	9.4	8.3 x 250	415	1.8
Ring-ring (baseline)	28.2	10 x 250	460	4.5
Ring-ring (ultimate)	114	10 x 250	937	9.2

Visual of the signal to background rate ratio with varying beam current and machine luminosity

- Assume a gas density of 2.65×10^{10} molecules/cm^2 over 10m



A word on machine design plans

- Will show results for both linac-ring and ring-ring designs
- Note the difference between low risk/baseline and ultimate design
- Current BNL strategy is to put forth the lowest risk machine possible in both scenarios (linac-ring and ring-ring), and then plan to upgrade over time
  - Difference between linac-ring low risk and ultimate design is the implementation of CeC to shrink beam size and increase luminosity
  - Difference between ring-ring baseline and ultimate is to increase the rep. rate to drive up the luminosity

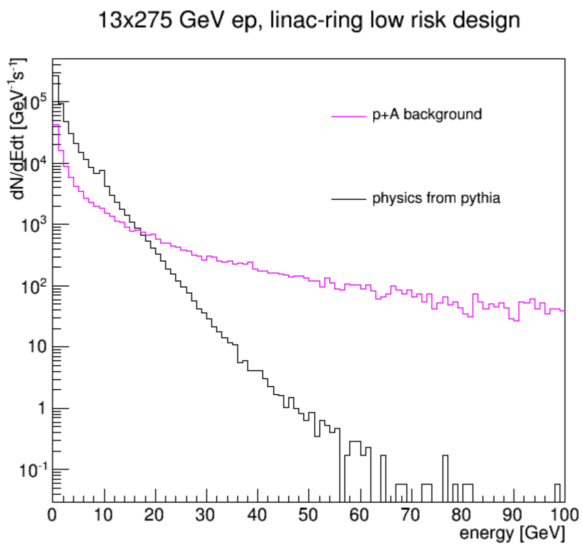
Comparing overall background rates to physics rates

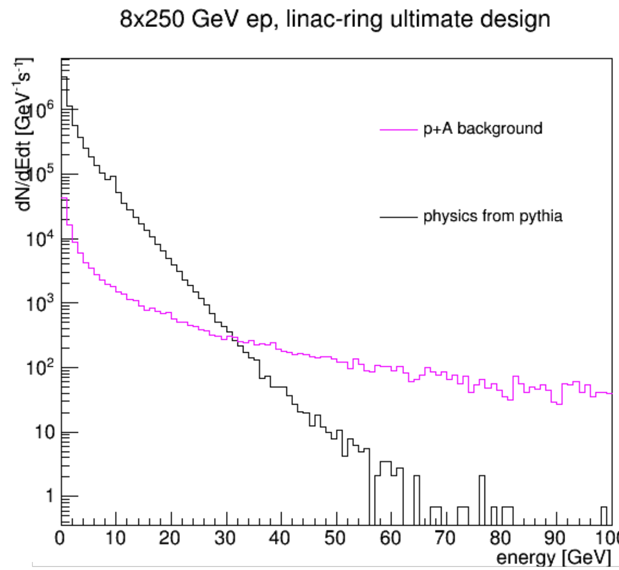
Machine Design	p+H^2 cross section [mb]	Background Lumi [x 10^{29} cm^{-2}s^{-1}]	e+p cross section [mb]	Machine Lumi [x 10^{33} cm^{-2}s^{-1}]
Linac-ring (low risk)	60	1.8	0.05	1.2
Linac-ring (ultimate)	60	1.8	0.05	14.4
Ring-ring (baseline)	60	4.5	0.05	1.1
Ring-ring (ultimate)	60	9.2	0.05	12.4

Machine Design	Background rate [kHz]	DIS rate [kHz]	Physics/BG ratio
Linac-ring (low risk)	11	58	5.3
Linac-ring (ultimate)	11	700	64
Ring-ring (baseline)	24.5	53	2.2
Ring-ring (ultimate)	55.6	603	11

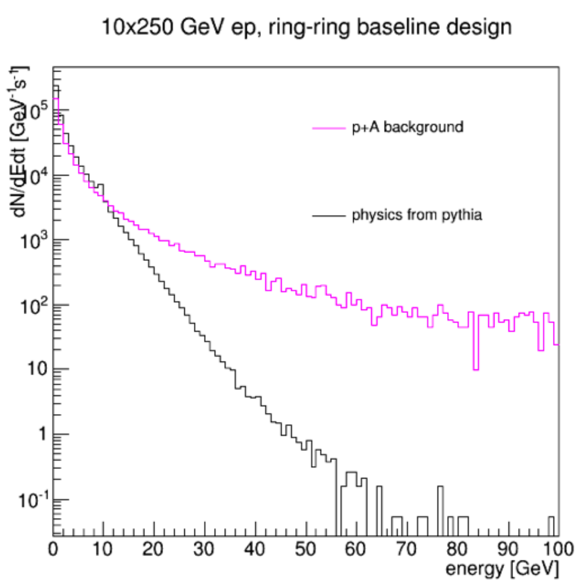
Comparing the energy spectra of background and DIS normalized by overall rates

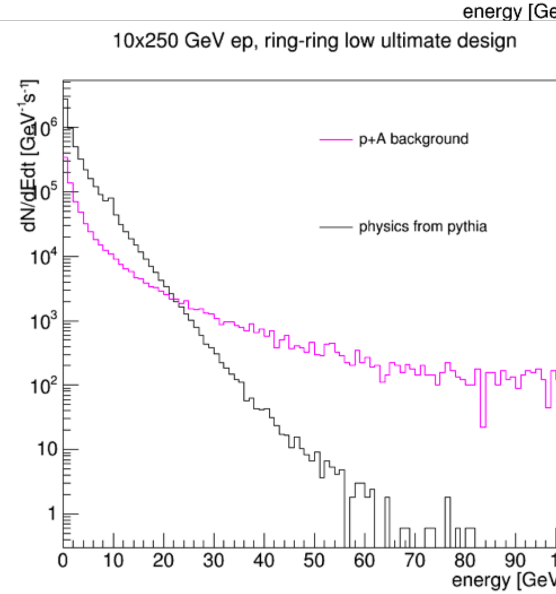
LRv3





RRv2





Estimate the probability of a DIS event to be "spoiled" by background

- Strategy: assume a reasonable time window around which an event is read into detectors (for now 10 ns)
  - Further, assume that a DIS event occurred in the middle of the window
  - Calculate the time it takes the particles in background events to reach the detector volume (assuming velocity the speed of light and a straight line path from the particle vertex to the point of entry in the detector)
  - If this time is less than than the event window, it means the background particle will be counted in the DIS event record and the event is polluted
  - The proportion of background events that then have some threshold number of particles in the detector during that time is calculated
  - The proportion is further adjusted for the relative rate of rates to account for the probability of actual event occurance

Machine Design	Event overlap probability (>1 particle)	Event overlap probability (>5 particles)
Linac-ring (low risk)	0.10	0.08
Linac-ring (ultimate)	0.008	0.006
Ring-ring (baseline)	0.2	0.09
Ring-ring (ultimate)	0.04	0.02

Conclusions

- Full report submitted to the Generic Detector R&D advisory committee
  - https://wiki.bnl.gov/conferences/images/6/69/ERD19_progressReport_Jan2017.pdf
- Find that overall, the linac-ring design is better in terms of reduction of p beam-gas background on main detector
  - Combination of higher luminosity with lower beam current
  - Probably having magnets right before the detector helps limit the acceptance of background particles as well
- The rates of the background events dominate at high particle energy
- The probability of event overlap could be a problem for analyses in the baseline designs
  - Further study needed to evaluate impact to analyses
  - This study allows us to start and think about mitigation strategies, i.e. masks, veto walls, etc.

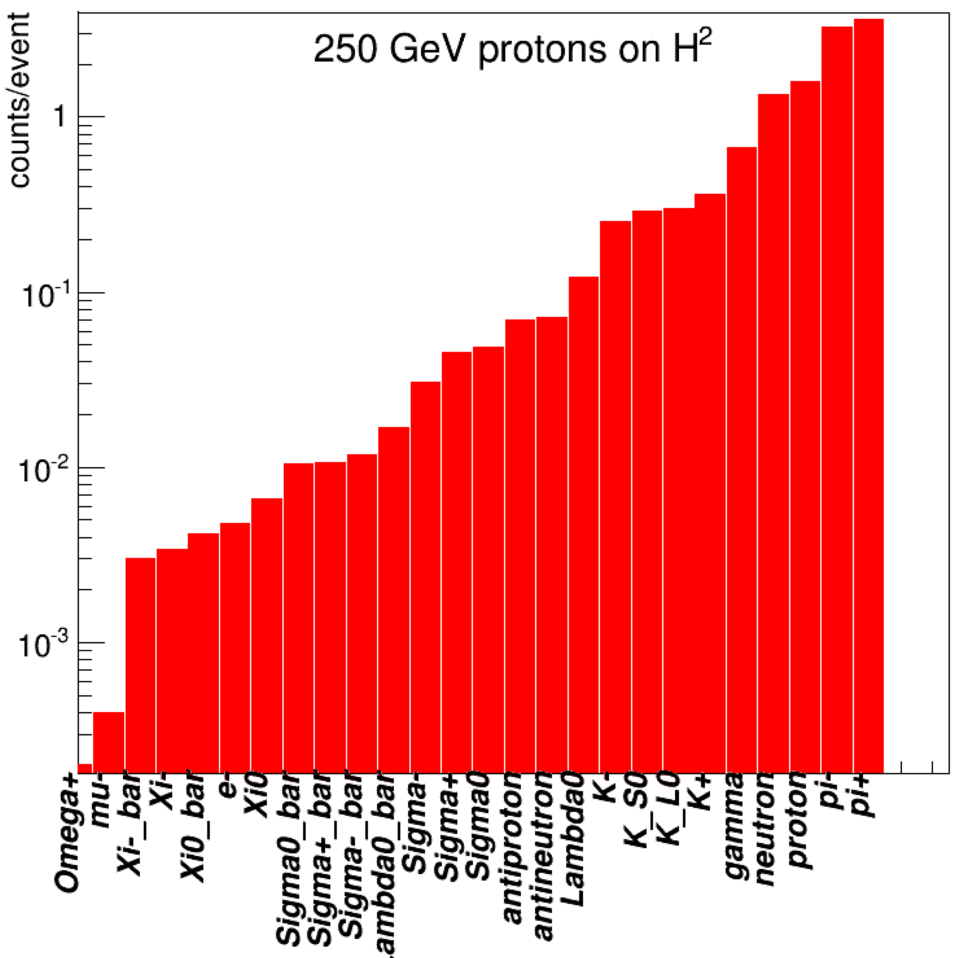
Expected Future Improvements

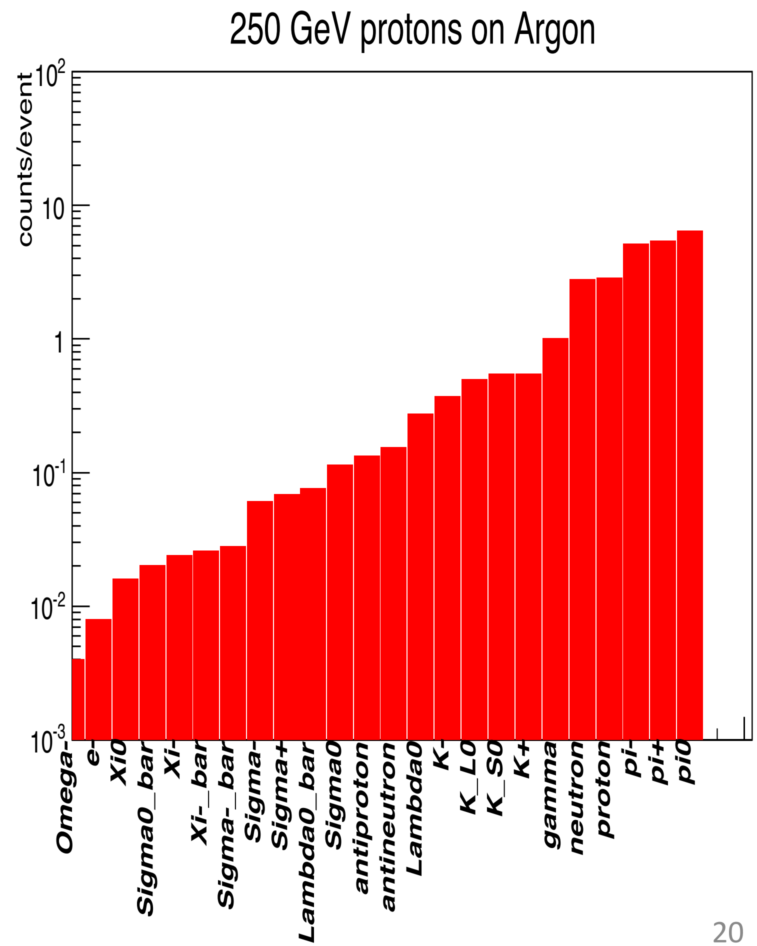
- Include secondaries produced from interaction with the magnet bulk
  - Reconsider the physical size of the magnets around the aperture
- Repeat the study for lower beam energies
- Fold in simulations with higher gas mass for a realistic gas composition
- Look more differentially into the composition of the particles and where they hit the detector
  - Like photons from background hitting the endcap calos
- Evaluate e beam-gas effects

Backups

p+H² and p+Ar species distributions

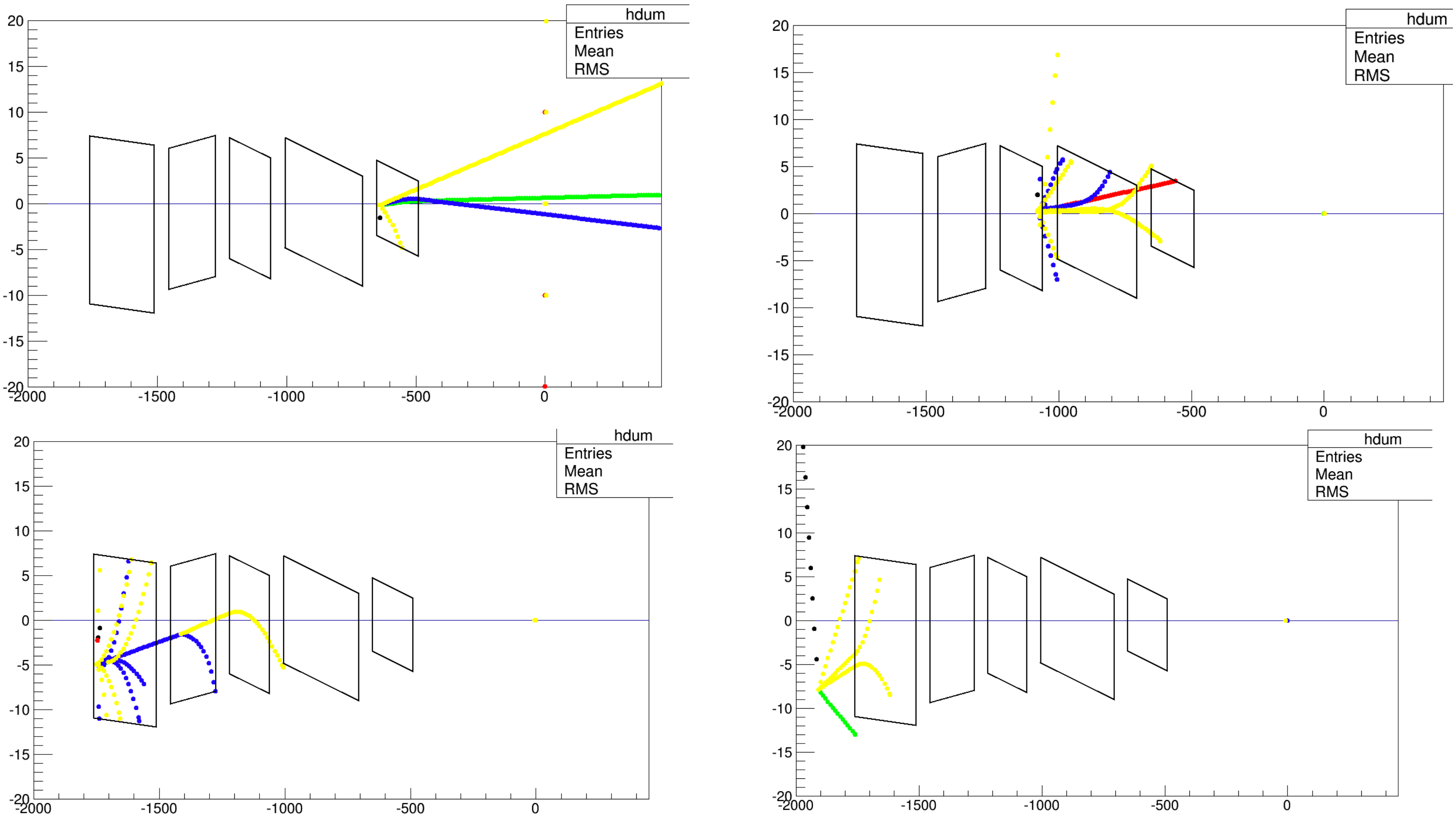
- 250 GeV p beam in both cases



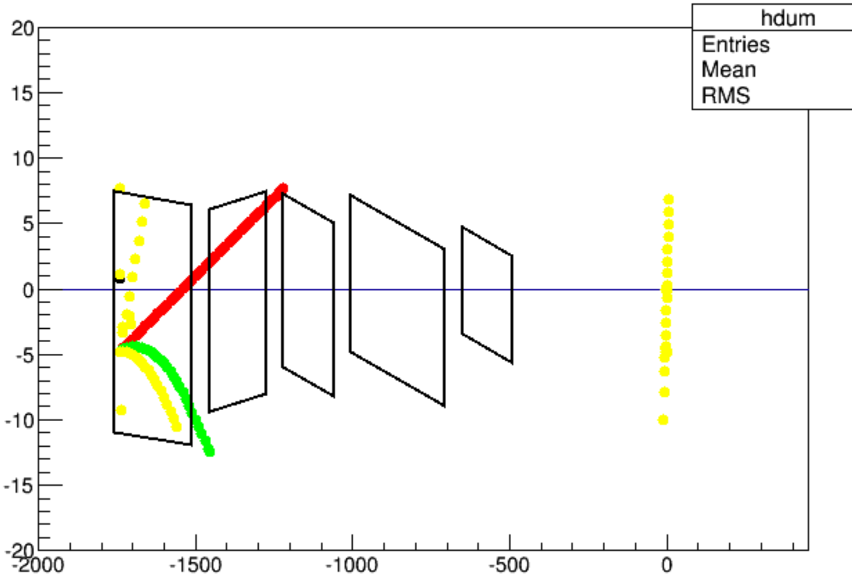


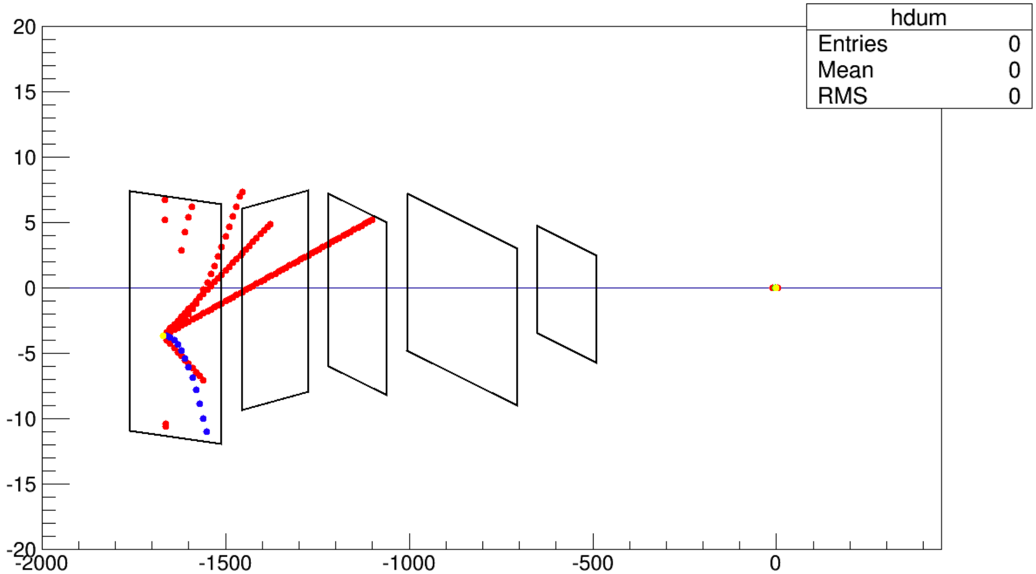
Ensuring collisions are properly oriented along the beam orbit

- Plot a few of the tracks in some events…look to make sure that it looks like the incoming proton is along the beam orbit…looks good



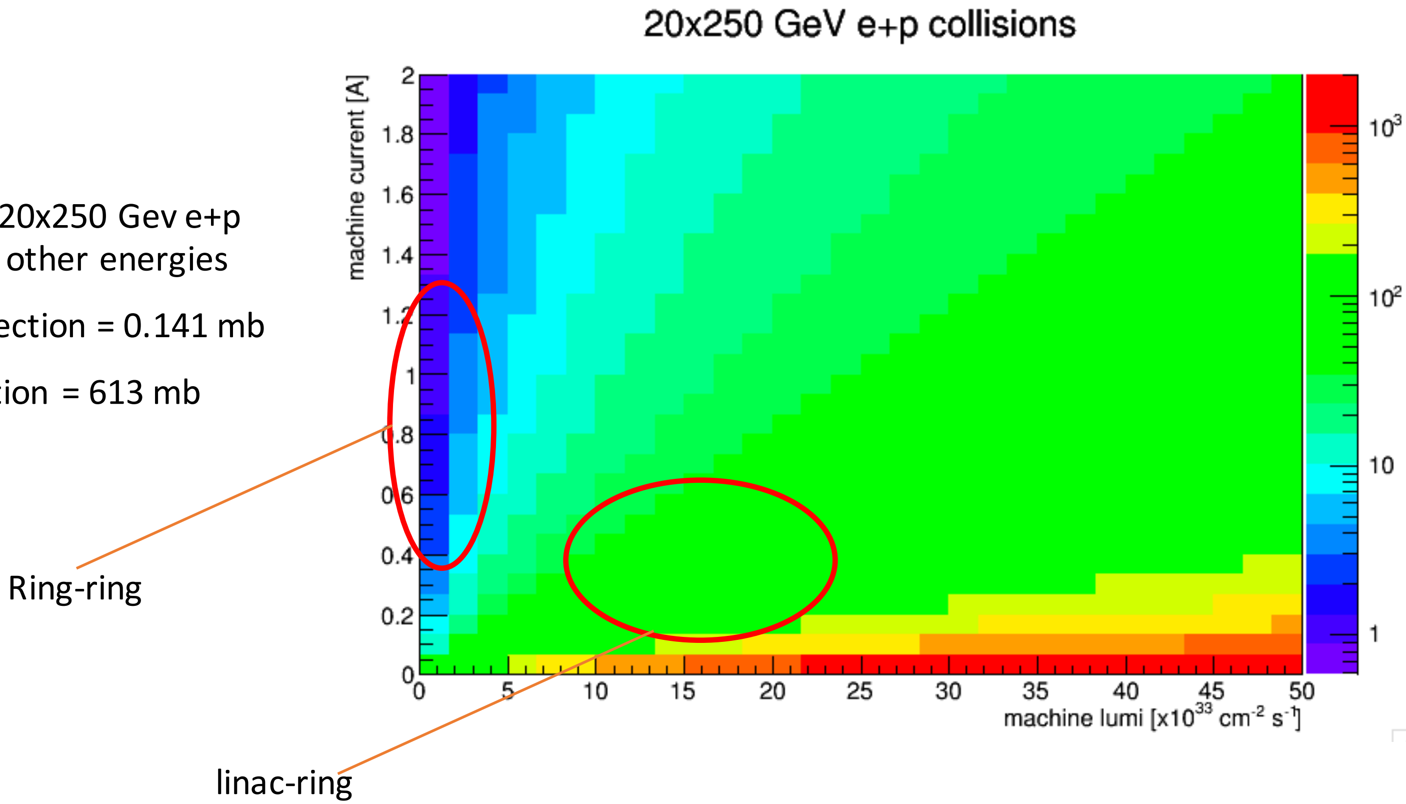
A few more plots for the cross check





Relation between machine current, luminosity and signal to background rate

- Only done for the 20x250 Gev e+p case…will redo for other energies
- Use pythia cross section = 0.141 mb
- Use p+A cross section = 613 mb



Fraction of background events with particles in the detector

- In the detector defined as within |z| < 4.5 m and radius > 2 cm